MODEL QUESTIONS
FREQUENTLY ASKED

1a) Explain the methods that are used for determining the grain size. (8M)
1b) Why alloying is done to metals? What are its limitations?(8M)(VVIMP)

2a) Describe the mechanism of crystallization process.(8M)
2b) What are the three basic methods for grain size estimation? (8M+8M)(VVIMP)

3a) Explain about the necessity of alloying. Why alloys are more preferred over metals, for industrial applications?
3b) Name Hume-Rothery's rules and explain all of them. (8M+8M)(VVIMP)

4Define covalent and metallic bonds in solids.(6M)

5a) Draw the close packed planes and directions in simple cube, BCC and FCC crystals and find out the Miller indices of the planes.(VVIMP)
(8M)
5b) Explain briefly the various types of crystal imperfections, with the help of neat sketches(VVIMP)
(8M)
6. a) Explain Hume - Rotherys rules for the formation of substitutional solid solutions (8M)

7What are the types of bonds? Explain their properties.(8M)(VVIMP)

8a) Explain metallic bond in detail. [3M]
8 b) What is an alloy? What is the need for alloying?(8M)

9 Define grain growth.(4)

Bonds in Solids :- Electrostatic force of attraction holds between the atoms in a solid material. This force is called as bond.

→ Bonding determines crystal structure

→ Crystal structure determines properties

Types of Bonds : Two Types

PRIMARY BONDS
i) Ionic Bond
ii) Covalent Bond
iii) Metallic Bond

SECONDARY BONDS
i) Vanderwall's Bond
ii) Hydrogen Bond.

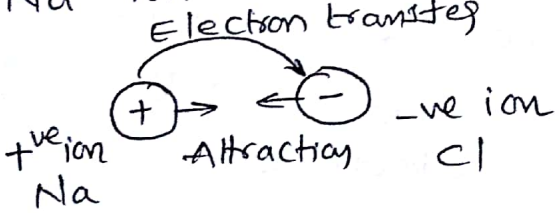
PRIMARY BONDS

(i) Ionic Bond

→ Forms by transferring an electron from one atom to another atom.

→ Ex: NaCl

Sodium transfers electron to chlorine. Then sodium becomes positive ion & chlorine becomes negative ion. Then the electrostatic force of attraction forms between Na^+ ion & Cl^- ion



Properties.

→ High melting point.
→ High hardness
→ High brittleness
→ Low electrical conductivity
→ Transparent to light.
→ Non directional.

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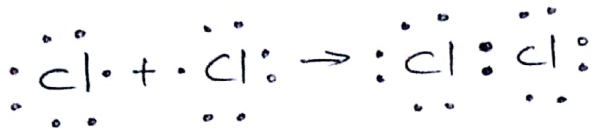
(ii) Covalent Bond

→ Forms by sharing of electrons between atoms

→ Ex: H_2, Cl_2, graphite, Diamond e.t.c.



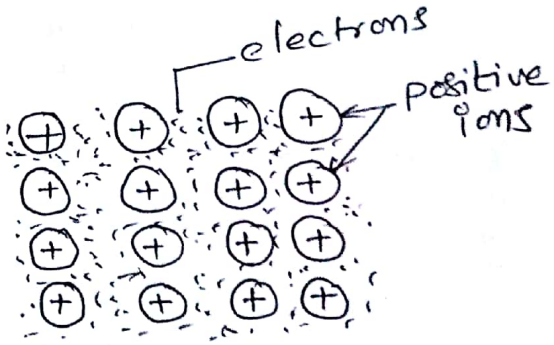
Properties of Covalent Bond

→ Very high melting point
→ Very high Hardness
→ Very high brittleness
→ Medium electrical conductivity
→ Opaque to light
→ Directional bond in nature

(iii) Metallic Bond

→ In metallic materials atoms are surround by ocean of electrons. And these electrons are ~~also~~ come out of these atoms, ~~due~~ because atoms will readialy loose electrons at room temperature itself.

→ So atoms become positive ions. And there is electrostatic force of attraction generates b/w thes +ve ions & electrons.



Properties of Metallic Bond

→ High Ductility
→ High Malleability
→ Low Hardness
→ Low Brittleness
→ High electrical & thermal conductivity
→ Non directional in nature
→ Opaque to light
→ Melting point is slightly less than in ionic Crystals.

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SECONDARY BONDS

(i) Vander Wall's Bond

→ the electrostatic force of attraction between the atoms or molecules, due to assymetric charge distributions in the atoms & molecules.

→ Gases such as O_2, N_2 & inert gases have crystalline form at very lower tempeatures, due to this type of bon

Properties of Vander Wall's Bond

→ Weak bond
→ Transpeqant to light
→ low melting point.

(ii) Hydrogen Bond

→ This is dipole-dipole bond i.e it forms b/w a '+ve' hydrogen ion & a '-ve' oxygen ion (i.e O^{2-})

→ Example is the attraction between hydrogen and oxygen among molecules of wateq.

Properties of Hydrogen bond

→ stronger than vander Wall's Bond.
→ High electrical conductivity
→ Low thermal conductivity.

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Crystalline Solids Vs Amorphous Solids

CRYSTALLINE SOLIDS	AMORPHOUS SOLIDS
→ Regular (ordered) arrangement of atoms	→ Random (Disordered) arrangement of atoms
→ Anisotropic in nature	→ Isotropic in nature
→ These having definite melting point	→ Don't have definite melting point
→ Ex: Copper	→ Ex: Glass.

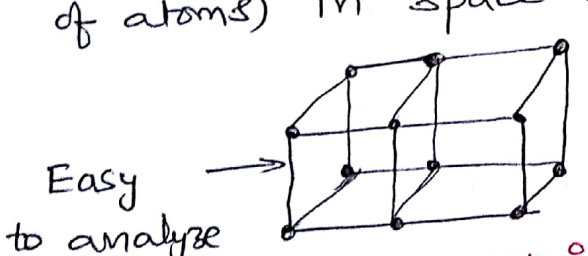
Crystal Structure

→ Crystals structure is orderly arrangement of atoms in a crystal.

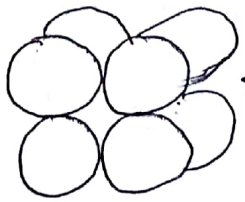
→ Ex: BCC, FCC, HCP, BCT e.t.c.

Space Lattice

→ three dimensional arrangement of lattice points (centres of atoms) in space is called space lattice.



Arrangement in Space lattice

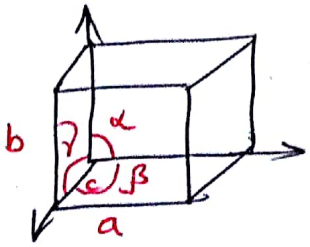


← Tough to analyse.

Real arrangement

Unitcell

→ The smallest volume of space lattice, which represents whole crystal structure



Lattice parameters
a, b, c
α, β, γ.

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Coordination Number :- (CN) :-

→ The number of neagest neighbours to a atom in a crystal structure.

→ CN for BCC = 8
for FCC = 12
for HCP = 12
for SC = 6

Packing factor (P.f) or (Packing density)

→ Ratio of total volume of atoms in a unit cell to volume of unit cell

$$P.f = \frac{n \times \frac{4}{3}\pi r^3}{a^3}$$

a = lattice parameter
n = effective no. of atoms
r = radius of atoms.

SC, BCC, FCC, HCP

	n	Pf	CN	Ex
SC	1	0.52	6	polonium
BCC	2	0.68	8	Cr, Mo, Na, W, Ta, Va
FCC	4	0.74	12	Al, Cu, Au, Pb, Ni
HCP	6	0.74	12	Cd, Zn, Mg, Co, Tp

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CRYSTAL DEFECTS

→ Crystals are rarely perfect in nature
→ Due to this, actual stength of material is much less than theoretical strength.

Types of Crystal Defects – Point, Line, Surface, Volume Defects

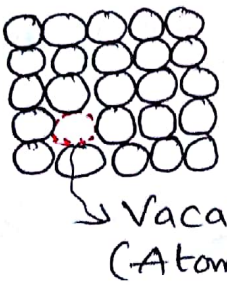
(I) Point Defects

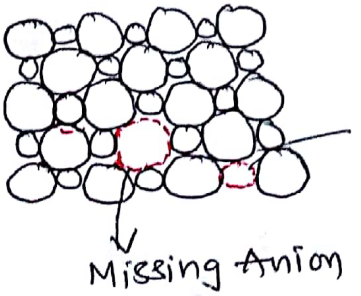
→ Zero dimensional defects.
→ Arises due to a atom mostly

Point Defects.

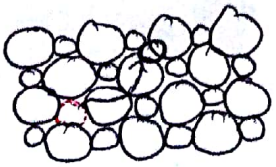
- Vacancy
  - Schottky Defect
  - Frankel Defect
- Substitutional Defect
- Interstitial Defect.

(i) Vacancy – Missing of an atom from normal site.





SCHOTTKY DEFECT – Pair of vacancies caused by removal of +ve & -ve ions to make neutrality.



Frankel DEFECT – Ion moves to interstitial site from normal site.

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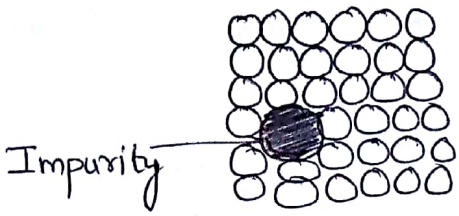
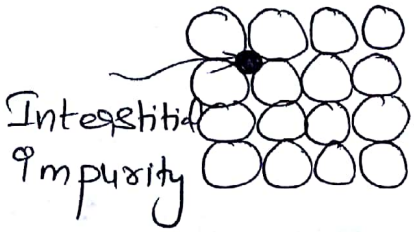
(ii) Substitutional Defect

→ forms when an atom in lattice is replaced by other different atom, which may be impurity or intensionally added alloyin element.



(iii) Interstitial Defect

→ When an extra atom is inserted into interstitial site



(II) LINE DEFECTS

→ One dimensional defects.

→ Reduces strength of materials.

Line Defects

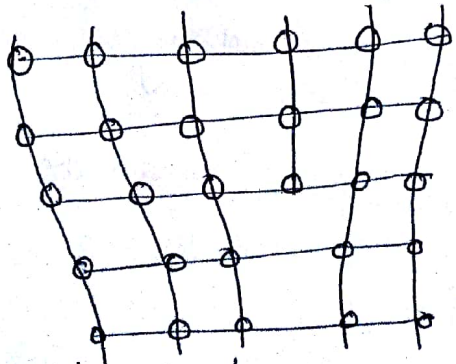
↓

Dislocations

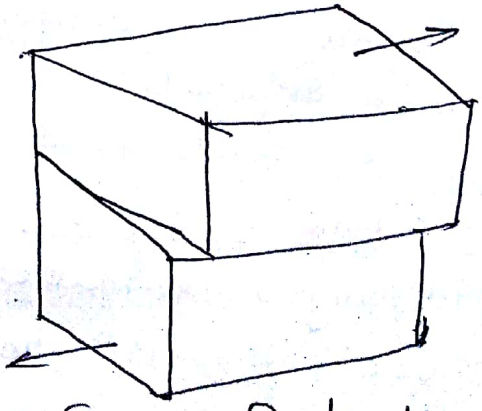
↓

Edge Dislocation (Extra plane of atoms in crystal)

Screw Dislocation, (Displacement of atoms in two seperate planes)



Edge Dislocation.



Screw Dislocation

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(III) SURFACE DEFECTS — Stacking Fault, Grain, Twinned Boundaries

Stacking Fault →

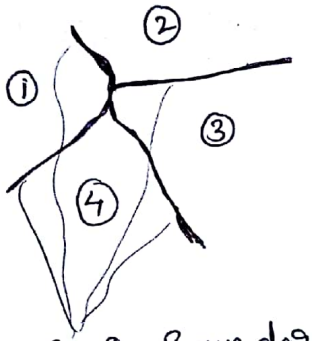
→ Missing a atomic plane from normal sequences

→ Ex: ABC ABC ABC.... Original Sequence

ABC BC ABC.... Defected Sequence
('A' Atomic plane Missed)

Grain Boundary

→ It is a narrow region between two grains of about two to few atomic diameters width.



Four grains ①, ②, ③ & ④.

Grain Boundaries

→ Atoms are irregular at grain boundaries than the atoms in grains. Thus atoms along the grain boundary has higher energy than those within grains.

Grain Boundary Types

- Low Angle Grain Boundary (Orientation b/w grains $< 10^{\circ}$)
- High Angle Grain Boundary (Orientation b/w grains $> 10^{\circ}$)

Twinned Boundary

→ Surface imperfection
→ which seperate two orientations that are mirror image of one another is called twin boundary

(IV) Volume Defects

→ Missing bulk matter (atoms) from the material.
→ these defects produces voids.

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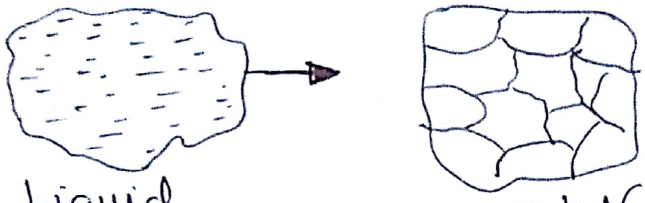
Crystallisation (Solidification) of metals



→ It is the process of change from liquid phase to solid phase.

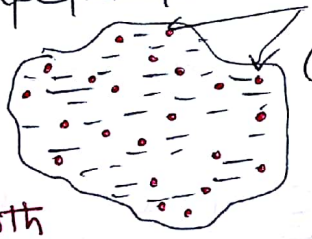
Steps of Crystallisation

→ 1. Nucleation
→ 2. Grain growth

Step 1 : Nucleation

→ In this step nuclei generates in liquid molten metal at different positions.

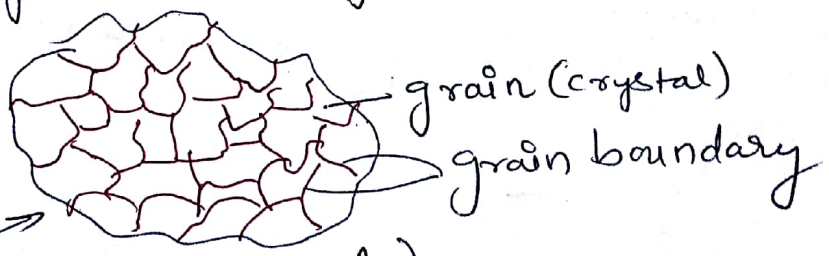
→ to form nuclei, have to cool the molten metal below freezing temperature.



Step 2 : Grain Growth

→ As cooling continous, more atoms tends to freeze and they may attatch to already existing nuclei.

→ Each nucleus grows into crystal as shown below.



called as → solid (polycrystalline material)
(Due to more no. of crystals)

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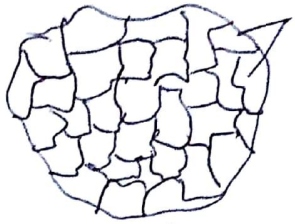
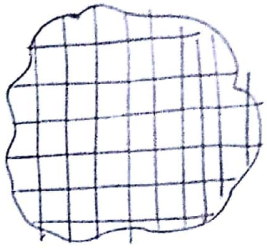
Factors affecting grain Size

Grains →

→ The crystals in polycrystalline metals are irregularly arranged as shown below (i) and these are called grains

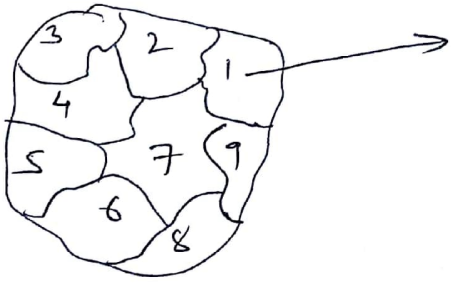


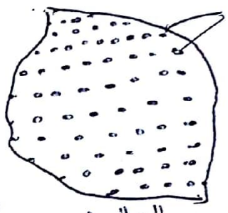
Irregular Arrangement (Always forms like this) (i)



Regular Arrangement (Never possible like this) (ii)

→ But within grain atoms are arranged regularly, in a ordered pattern as shown in below diag.





[grain "1" enlarged]
[Atoms are in order]

Grain Boundaries

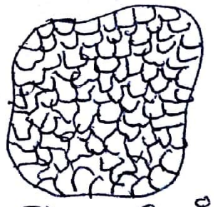
Read from page No (8) [∴ Crystal Defects Doc]

Factors affecting the grain Size

Coarse Grained Structure →

→ To get coarse grained structure, i.e as shown below, in fig (i)

Coarse grained (Large) Structure
Fig (i)



Fine grained (Small) Structure
Fig (ii)

Crystal growth must be high compared to rate of nucleation.

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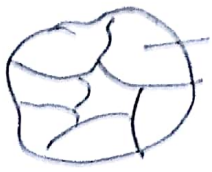
→ To get fine grained structure as shown in above fig (ii), rate of nucleation must be high compared to rate of crystal growth. Then only there would be no space available for ~~grow~~ nuclei to grow into a bigger crystal.

Coarse Grain Structure



→ Rate of Crystal Growth > Rate of Nucleation

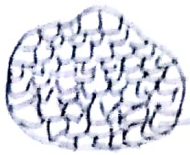
→ Slow Cooling produces Coarse grains (Annealing)

→ Length of grain boundary is small

→ strength is low
(Acc. to Hall-Petch Relation)
$\downarrow \sigma \propto \frac{1}{d} \uparrow$

Fine Grained Structure

→



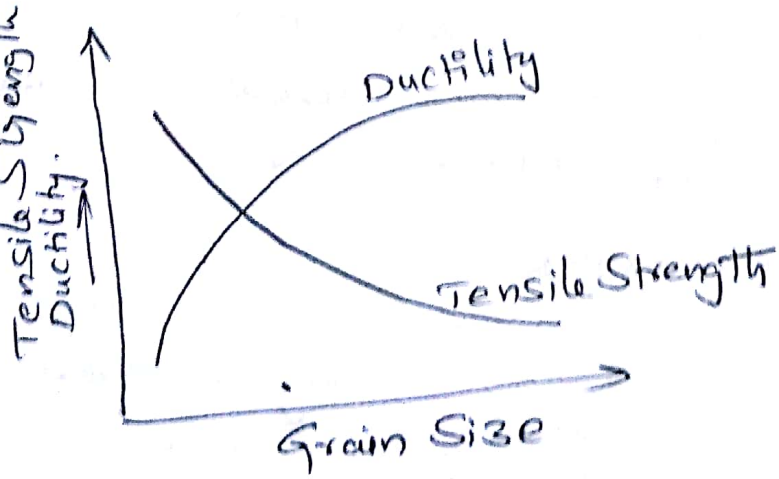
→ Rate of Nucleation > Rate of Crystal growth

→ Rapid cooling produces fine grains (Normalizing)

→ Length of grain boundary is large

→ Strength is high.
$(\uparrow \sigma \propto \frac{1}{d} \downarrow)$

Grain Size Vs Tensile Strength, Ductility



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Methods to Determine Grain Size

1. Comparison procedure
2. planimetric procedure
3. Intercept procedure
4. ASTM Method

→ the above three methods are majorly used to determine or compare grain size

→ To find the grain size of a single phase, any one method is sufficient.

→ To find the grain size of a multiphase (Two or Three phase) combination of methods are needed.

1. Comparison Method

→ No need of counting grains, intercept or intersections.

→ Involves comparision of grain structure to a series of available data.

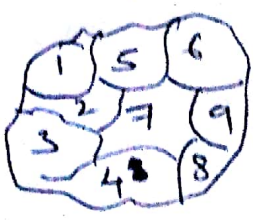
→ Usually with this method, there is a chance of producing error in measuring grain size.

2. planimetric Method (fig(i))

→ This method involves an actual count of the no. of grains in a known area. The no. of grains in a unit area N_A, is used to determine ASTM grain size number (N)

3. Intercept procedure

→ This method involves an actual count of no. of grains intercepted by a test line or the no. of grain boundary intersections with test line



No. of Grains = 9

← planiMetric Method
fig (i)

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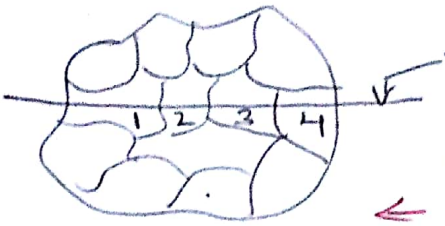


No. of Grains = 4

← Intercept procedure

fig(ii)

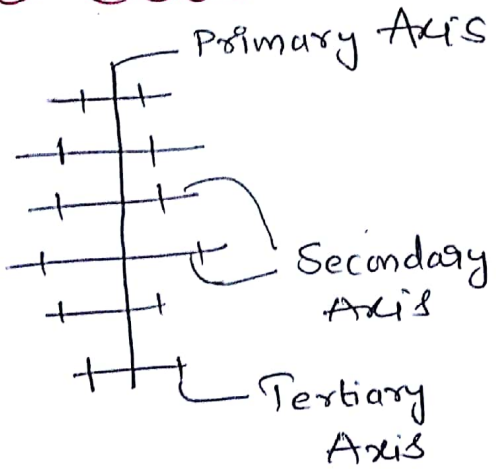
4. ASTM Method

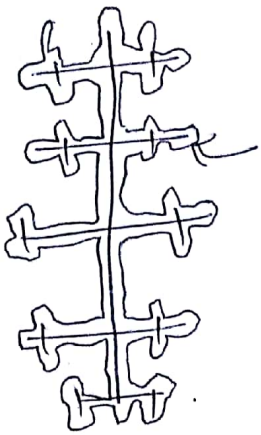
$$N = 2^{n-1}$$

N = No. of grains / in^2 at 100 X Magnification

n = ASTM grain size.

Dendritic Growth :- Tree Like Structure





→ Almost All metal castings are formed with dendritic growth mechanism in the process of crystallization

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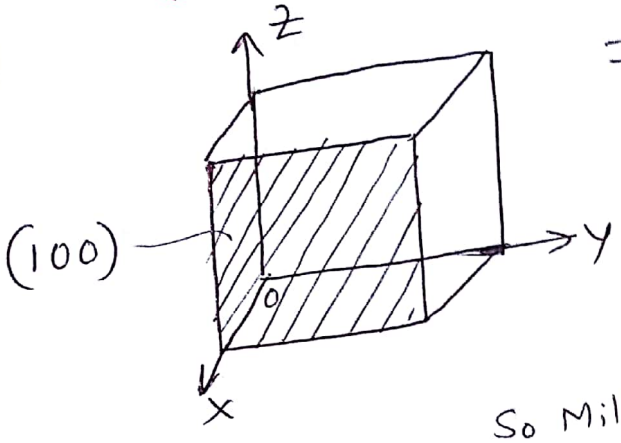
MILLER INDICES

(h k l) ← plane notation

[h k l] ← Direction notation

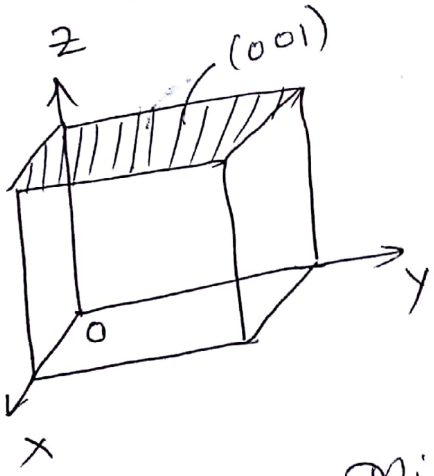
{h k l} ← Family of planes notation

(i)



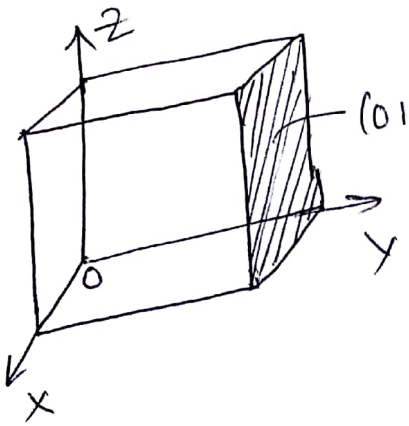
Intercept along
x, y, z → 1, ∞, ∞
Reciprocals for intercepts
→ $\frac{1}{1}, \frac{1}{\infty}, \frac{1}{\infty}$
→ 1, 0, 0
So Miller Indices → (1 0 0)

(ii)



Intercepts along
x, y, z → ∞, ∞, 1
Reciprocals for intercepts
→ $\frac{1}{\infty}, \frac{1}{\infty}, \frac{1}{1}$
→ (0, 0, 1)
Miller Indices (0 0 1)

(iii)



Intercepts along
x, y, z → ∞, 1, ∞
Reciprocals for intercepts
→ $\frac{1}{\infty}, \frac{1}{1}, \frac{1}{\infty}$
→ 0, 1, 0
Miller Indices (0 1 0)

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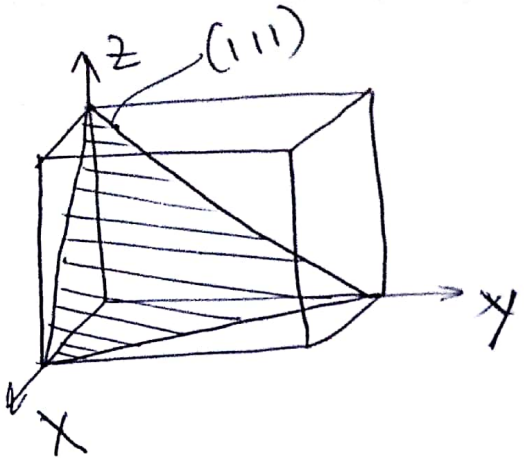
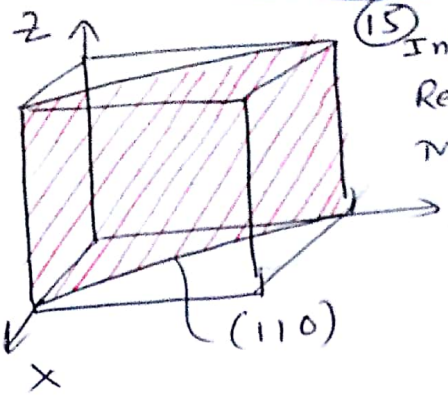
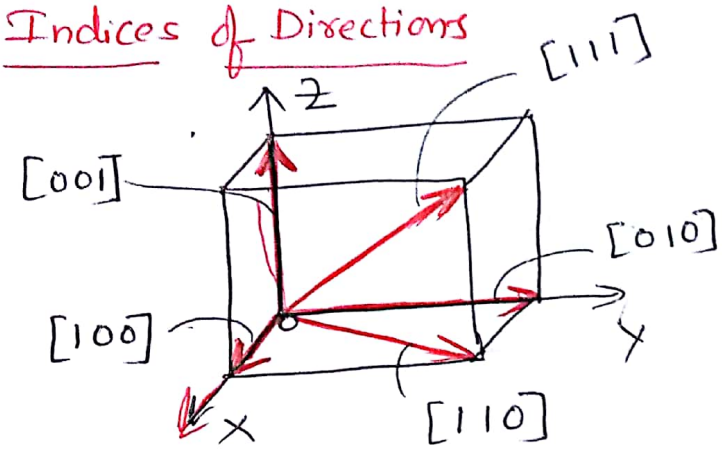




(15) Intercepts → 1, 1, ∞
Reciprocals → 1, 1, 0
Miller Indices (1 1 0)

Miller Indices of Directions



FCC close packed directions — [110]
close packed plane — (111)

BCC close packed direction — [111]
close packed plane — [110]

Scanned by CamScanner

Necessity Of Alloying, Types of Solid Solutions, Hume Ruthery Rules, Intermediate Alloy Phases, Electron Compounds:-

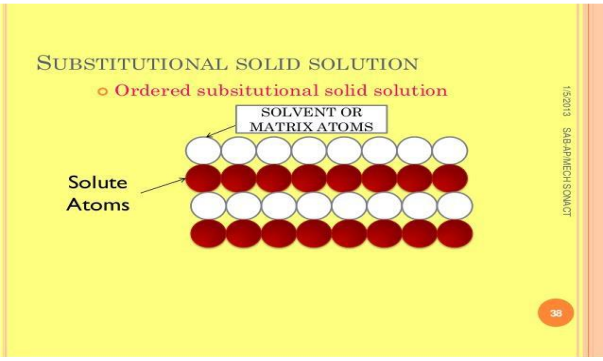
PURE METAL:- It is the metal, which consists of identical atoms.
EXAMPLE OF PURE METALS:- Copper, Nickel, Aluminum e.t.c
APPLICATION OF PURE METALS:-
The important uses of metals as pure metals are:
1. Copper and aluminum wire are used to carry electric current.
2. Copper, aluminium and iron are used to make domestic utensils and factory equipment.
3. Thin foils of aluminium are used for wrapping cigarettes, medicines, confectionery, etc.
4. Aluminium is used for making angles, doors, pipes, etc. which are used in the construction of houses.
5. Metals such as sodium, titanium, zirconium, etc. are used in generation of nuclear energy and in space science projects.
6. Mercury is used in thermometers.
7. Gold and silver metals are used to make jewellery.
8. Uranium metal is used to generate nuclear energy.
9. Titanium metal is very hard, resistant to corrosion, light, has high melting point and is good conductor of heat and electricity. Because of its unique and useful properties titanium is sometimes called 'the wonder metal'.
10. Titanium and its alloys are extensively used in:
(i)Jet and gas turbine engines.
(ii)Aircrafts frames.
(iii)Marine equipment.
ALLOY:- It is defined as a material, which is composed of two or more than two elements and among which one must be a metal. The element, which is in major quantity, is called as '*base metal*".
ALLOYING ELEMENTS:- The elements that are used to make alloy are called alloying elements.
EXAMPLES OF ALLOYS:- Brass, Bronze, Gun metal, Steel, Duralumin e.t.c
NECESSITY OF ALLOYING:- We unable to get the required properties(e.g strength, smooth surface e.t.c) with pure metals. So alloying elements are added to achieve the desired properties. The reasons for alloying elements may be one or more of the following
1)To improve corrosion resistance.
2)To improve wear resistance.
3)To improve magnetic and electrical properties.
4)To improve strength and toughness.
5)To improve machinability, weldability and hardenability.
6)To improve hot hardness.
7)To improve hardness.
PHASE: - It is defined as a physically distinct and homogeneous portion of the system. A homogeneous system consists of same composition and same physical chemical properties throughout its volume. i.e. each point in the system represents same properties.

EFFECTS OF ALLOYING ELEMENTS:-

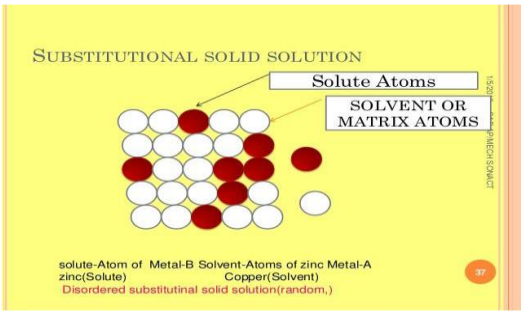
ELEMENT	EFFECT
Chromium	Improves corrosion and wear resistance and carbide former
Cobalt	Increases strength at higher temperatures
Copper	Improves corrosion resistance
Lead	Improves chip formation,and machinability
Manganese	Carbide former,and improves machinability and hardenability
Nickel	Improves strength and toughness Improves corrosion resistance and hardenability
Silicon	Improves fluidity in casting, strength and electrical conductivity
Phosphorous	Improves chip formation and machinability
Tungsten	Improves hot strength and hardness

SOLID SOLUTIONS:- It is a simplest form of alloy. It consists of two elements soluble in each other in solid state and exist in a single phase structure.
SOLVENT:- The major element in the solid solution is called as solvent.
SOLUTE:- The minor element in the solid solution is called as solute.

TYPES OF SOLID SOLUTIONS:-
(I)Substitutional solid solution
(II)Interstitial solid solution
(I)SUBSTITUTIONAL SOLID SOLUTION:-
Solute atoms can substitute for solvent atoms in a crystal lattice.The crystal structure of solvent is unchanged but the lattice may be distorted by the presence of solute atoms, particularly if there is a significant difference in atomic diameters of the solute and solvent.
We can divide substitutional solid solution into two types
(i)Ordered substitutional solid solution:- Ex: Cu-Au

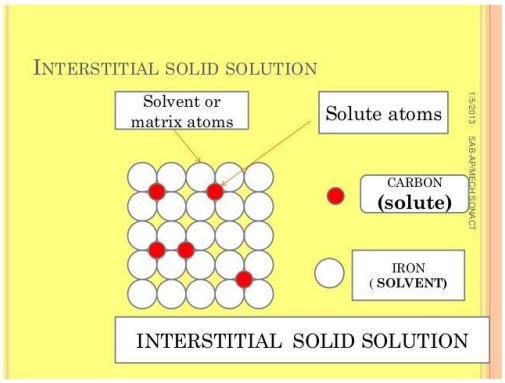


(ii)Disordered substitutional solid solution:- Ex:Cu-Ni, Cu-Zn



(II)INTERSTITIAL SOLID SOLUTION:-

Interstitial solid solution occurs when the solute atoms are very small(ex: Hydrogen, carbon, boron, oxygen) and fit into interstitial sites in the crystal lattice.



HUME-ROTHERY RULES:-

These rules are favored for extensive *solid solubility* of one element in another.

(i)***Size factor*:-**The diameter of the atoms of the elements must not differs by *more than 15%*

(ii)***Crystal structure:-***The crystal structure of the two elements must be same. Ex: Cu-Au, Cu-Ni

(iii) ***Valency factor***:- Two elements should have same valence.

iv)***Electro negativity:-*** There should be no appreciable difference in the electro negativity of the two elements. Otherwise solution is not formed.

INTERMEDIATE ALLOY PHASES:-

- If we try to add alloying elements to a solid solution more than its solid solubility then intermediate alloy phase forms.Ex:Fe_3C,W_2C e.t.c.
- Crystal structure and properties of materials are different from solid solutions.

- **TYPES OF INTERMEDIATE ALLOY PHASES:-**
- (I)Inter metallic compounds
- (II)Interstitial compounds
- (III)Electron compound

(I)INTER METALLIC COMPOUNDS:-

These are ionic or covalent solids, and these are non metallic in nature. They possess poor ductility or poor electrical conductivity, and may have complex crystal structure, ex:- CaSe, Mg_2Sn.

(II)INTERSTITIAL COMPOUNDS:-

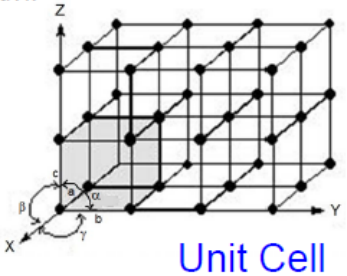
Interstitial compounds are formed between transition metals such as scandium(Sc),Titanium(Ti),Tantalum(Ta),Tungsten(w) and iron(Fe) with hydrogen ,oxygen, carbon, boron and nitrogen. Ex: TiC, TaC,CrN,W2C.These don't obey normal valence rules.

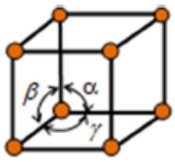
(III)ELECTRON COMPOUNDS:-

These are also don't obey normal valence rules. These are based on electron to atom ratio.
Examples:-3/2 electron to atom ratio compounds-CuZn, Cu3Al
21/13 electron to atom ratio compounds-Cu5 Zn8, Cu9Al4
7/4 electron to atom ratio compounds-CuZn3

Crystal Systems

- The space lattice points in a crystal are occupied by atoms.
- The position of any atom in the 3D lattice can be described by a vector $r_{uvw} = ua + vb + wc$, where u, v and w are integers.

(a) 

(b) 

Unit Cell

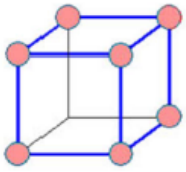
The three unit vectors, *a*, *b*, *c* can define a cell as shown by the shaded region in Fig.(a) This cell is known as unit cell (Fig. b) which when repeated in the three dimensions generates the crystal structure.

Bravais Lattice

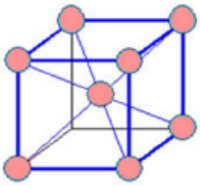
The unit vectors *a*, *b* and *c* are called lattice parameters. Based on their length equality or inequality and their orientation (the angles between them, α, β and γ) a total of 7 crystal systems can be defined. With the centering (face, base and body centering) added to these, 14 kinds of 3D lattices, known as ***Bravais lattices***, can be generated.

Crystal Systems

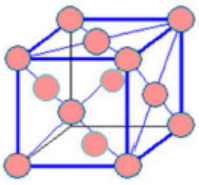
Cubic: $a = b = c$, $\alpha = \beta = \gamma = 90^o$



Simple cubic

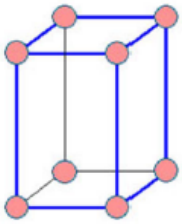


Body-centered cubic (BCC)

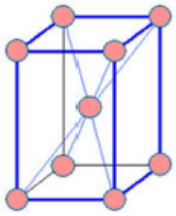


Face-centered cubic (FCC)

Tetragonal: $a = b \neq c$, $\alpha = \beta = \gamma = 90^o$

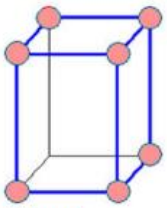


Simple Tetragonal

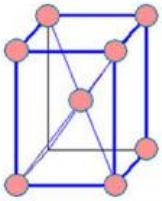


Body-centered Tetragonal (BCT)

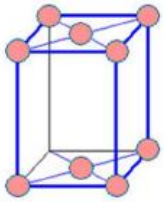
Orthorhombic: $a \neq b \neq c$, $\alpha = \beta = \gamma = 90^o$



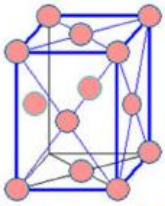
Simple



Body-centered

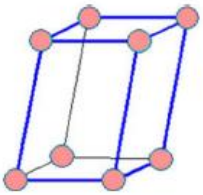


Base-centered

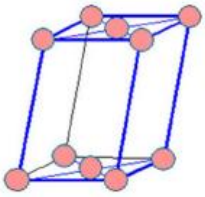


Face-centered

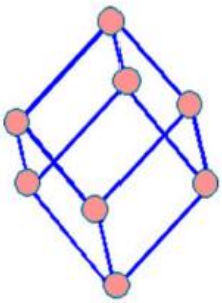
Monoclinic: $a \neq b \neq c$, $\alpha = \gamma = 90^o \neq \beta$



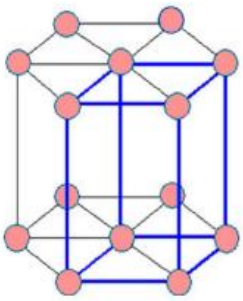
Simple monoclinic



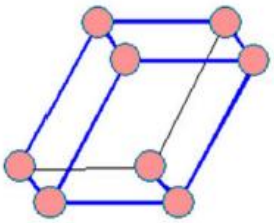
Base-centered monoclinic



Rhombohedral
$a = b = c$
$\alpha = \beta = \gamma \neq 90^o$



Hexagonal
$a = b \neq c$
$\alpha = \beta = 90^o \; \gamma = 120^o$



Triclinic
$a \neq b \neq c$
$\alpha \neq \beta \neq \gamma \neq 90^o$